APEX workshop 2012, 20.11.2012

Beam studies at the LHC

Giulia Papotti
for the LHC MD coordination

thanks to G. Arduini, W. Herr, W. Hofle, E. Shaposhnikova, …

acknowledgements

- thanks to all MD teams, machine experts and OP shift crews for the excellent work in preparing and executing the studies, analysing the results, the flexibility and the availability
- here a (non-exhaustive) list of all the contributors:
  - A. Antoine, T. Argyropoulos, R. Assmann, T. Baer, M. Barnes, W. Bartmann, H. Bartosik, P. Baudrenghien, D. Belohrad, C. Bhat, A. Boccardi, T. Bohl, C. Bracco, E. Bravin, R. Bruce, X. Buffat, S.Burger, F. Burkart, A.Burov, A. Butterworth, R. Calaga, E. Calvo Giraldo, M. Cauchi, S. Cettour Cave, K. Cornelis, D. Deboy, B. Dehning, F. Dubouchet, E. Effinger, J. Emery, S. Fartoukh, L. Ficcadenti, M. Gasior, R. Giachino ,M. Giovannozzi, B. Gorini, J.J. Gras, E. Griesmayer, A. Guerrero, M. Hempel, W. Herr, W. Hofle, G. Iadarola, M. Jaussi, V. Kain, R. Jones, M. Kuhn, M. Lamont, L. Lari, T. Lefevre, M. Ludwig, E. Maclean, A. MacPherson, R. De Maria, A. Marsili, T. Mastoridis, E. Metral, J. Molendijk, N. Mounet, G. Müller, J. F. Esteban Muller, G. Papotti, S. Bart Pedersen, T. Persson, T. Pieloni, M. Pojer, L. Ponce, V. Previtali, A. Priebe, A. Rabiller, S. Redaelli, G. Roy, R. Rosol, G. Rumolo, B. Salvachua, B. Salvant, M. Sapinski, F. Schmidt, E. Shaposhnikova, M. Solfaroli, G. Stancari, R. Steinhagen, H. Timko, R. Tomás, G. Trad, J. Tuckmantel, J. Uythoven, G. Valentino, A. Valishev, D. Valuch, G. Vanbavinckhove, W. Venturini, J. Wenninger, D. Wollmann, M. Zerlauth, F. Zimmermann
- apologies: later credits are far less thorough

outline

- current LHC parameters
- LHC schedule and LHC Studies Working Group
- typologies of MD requests and classification
- priorities for 2012 run
- many examples of LHC MDs
- ideas for studies at RHIC

LHC today

parameter	last week (typ. values)	design report
energy [TeV]	4	7
bunch spacing [ns]	50	25
number of bunches	1374	2808
bunch current [ppb]	1.60e11	1.15e11
norm. transverse emittance [um]	2.5	3.75
beta* [m]	0.6	0.55
peak inst. luminosity [$cm^{-2}s^{-1}$]	0.71e34 (best: 0.77e34)	1e34

- some of our secrets:
  - aperture
  - “tight” collimators
  - our injector chain
  - …

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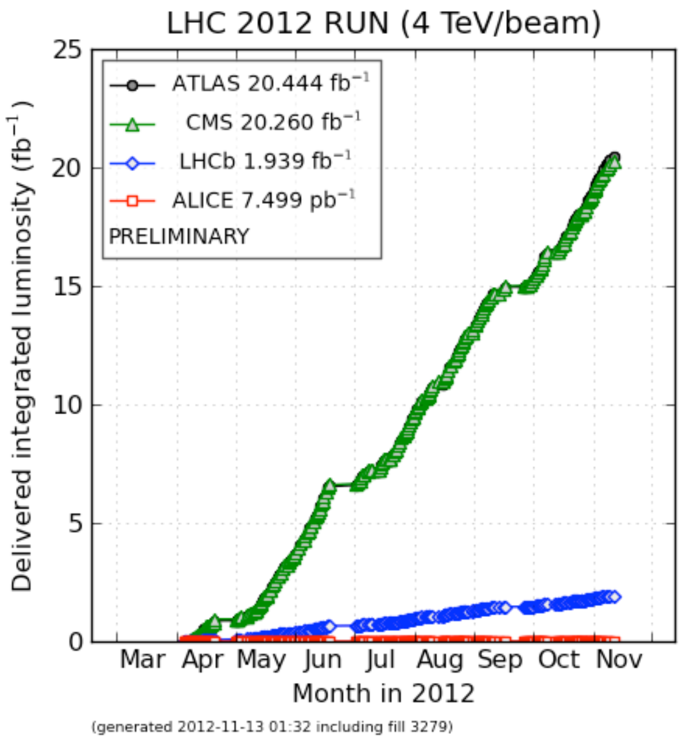

giulia.papotti@cern.ch

2012 LHC schedule

- 4 categories
  - physics production
    - incl. special runs
  - beam commissioning
  - technical stops
  - MDs
    - 4 long blocks and 4 days floating
    - fixed unless…
- total 22 days (420 h)
  - physics: 150 days
- requests >900 h
  - at start of year

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the CCC gets crowded

LHC Studies Working Group

- chairperson: F. Zimmermann
  - and R. Assmann until August 2012
- scientific secretary: G. Papotti
- mandate
  - collect MD requests, prioritize them
  - prepare MD schedules, propose it to LHC Machine Committee for approval

www.cern.ch/lhc-md

- meet for each MD
  - before: to discuss studies and priorities, optimize resources, prepare Machine Protection classification and beam requests to injectors
  - after the MD to review and ensure the documentation of results (MD notes)
- Machine Protection classification:
  - A: setup beam (max tot intensity: 5e11 p at 450 GeV and 3e11 at 4 TeV)
  - B: non-setup beam, but no changes to MP systems (e.g. collimators)
  - C: non-setup beam, changes to MP systems: MD plan to be written and approved
- short studies carried out outside of MD time: “operational developments”

MD categories and examples

- 76 requests already in Dec. 2011
- grouped per subject / system
  - collimation (11)
    - loss maps during the ramp with transverse damper
    - verify protection hierarchy with nominal gaps in mm
  - optics (9)
    - HL-LHC optics (Achromatic Telescopic Squeeze, beta*=10 cm)
    - beta*=40 cm with nominal optics
    - feasibility of high beta* (1 km)
  - RF and longitudinal dynamics (8)
    - batch-by-batch longitudinal blow-up at injection
  - impedance (8)
  - beam-beam (7)
  - quenches (6)
  - transverse damper (4)
  - injection (4)
    - transfer of SPS Q20 beams (smaller emittances and higher intensity)
  - ions or p-Pb (3)
  - …

priorities for 2012 run: examples

- for operation in 2012
  - compatibility between tune measurement and transverse damper
  - calibrate beam instrumentation (e.g. transverse emittance measurements)
  - understand the transverse instabilities
- for future running
  - quench tests: are the Beam Loss Monitor thresholds correctly set?
  - characterize operation with 25 ns beams (long-range beam-beam, e-cloud, UFOs, ...)
  - arc UFOs: will they be a limitation?
  - improve LHC injection limitations (2x more bunches down the transfer line with 25 ns)
- lower priority (no examples)

note: UFOs: Unidentified Falling Objects
creating fast and localized losses

2012 MD examples

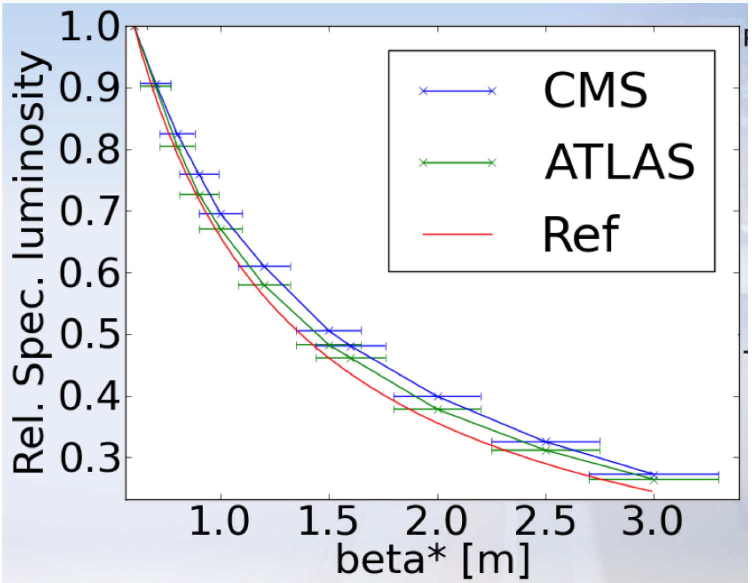
- (biased choice!)

- luminosity levelling with beta*
- instability threshold with octupole strength and chromaticity
- long-range beam-beam study
- transverse damper developments
- longitudinal dynamics: loss of Landau damping

luminosity levelling with beta* (1)

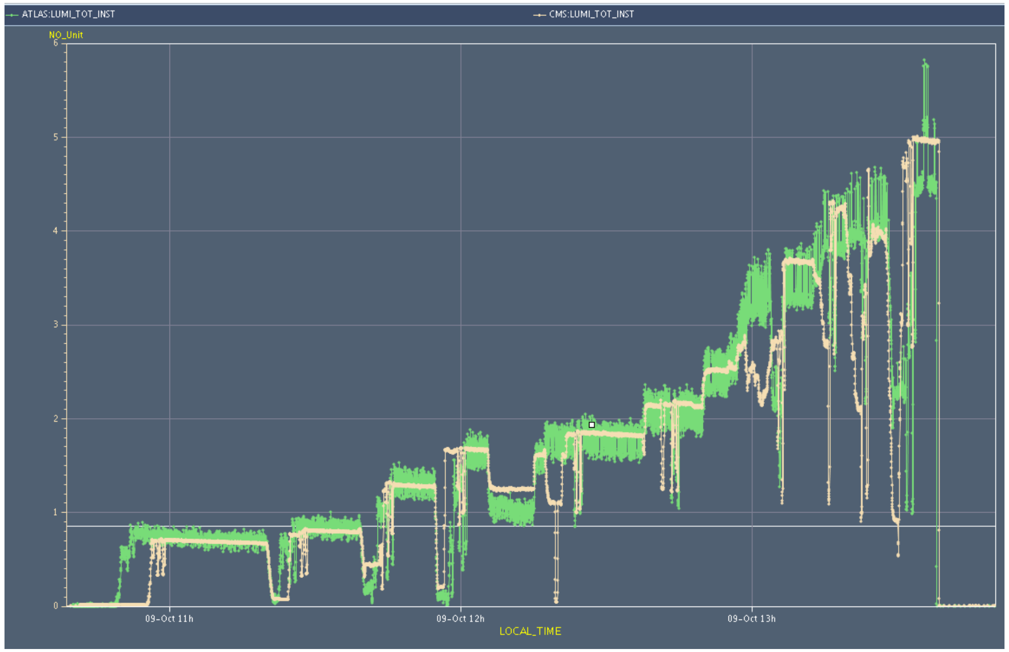
J. Wenninger,
S. Redaelli et al.

- motivation:
  - allows profiting from stabilization by head-on beam-beam earlier in the cycle
  - alternative to levelling by transverse offset for IP1&5 for future running
    - levelling by transverse offset is operational but has drawbacks
- first iteration: 3 m to 0.6 m
  - 2 fills with single bunches for settings, 1 fill with 36-b trains to validate procedure
  - good reproducibility, no show stoppers found



luminosity levelling with beta* (2)

J. Wenninger,
S. Redaelli et al.



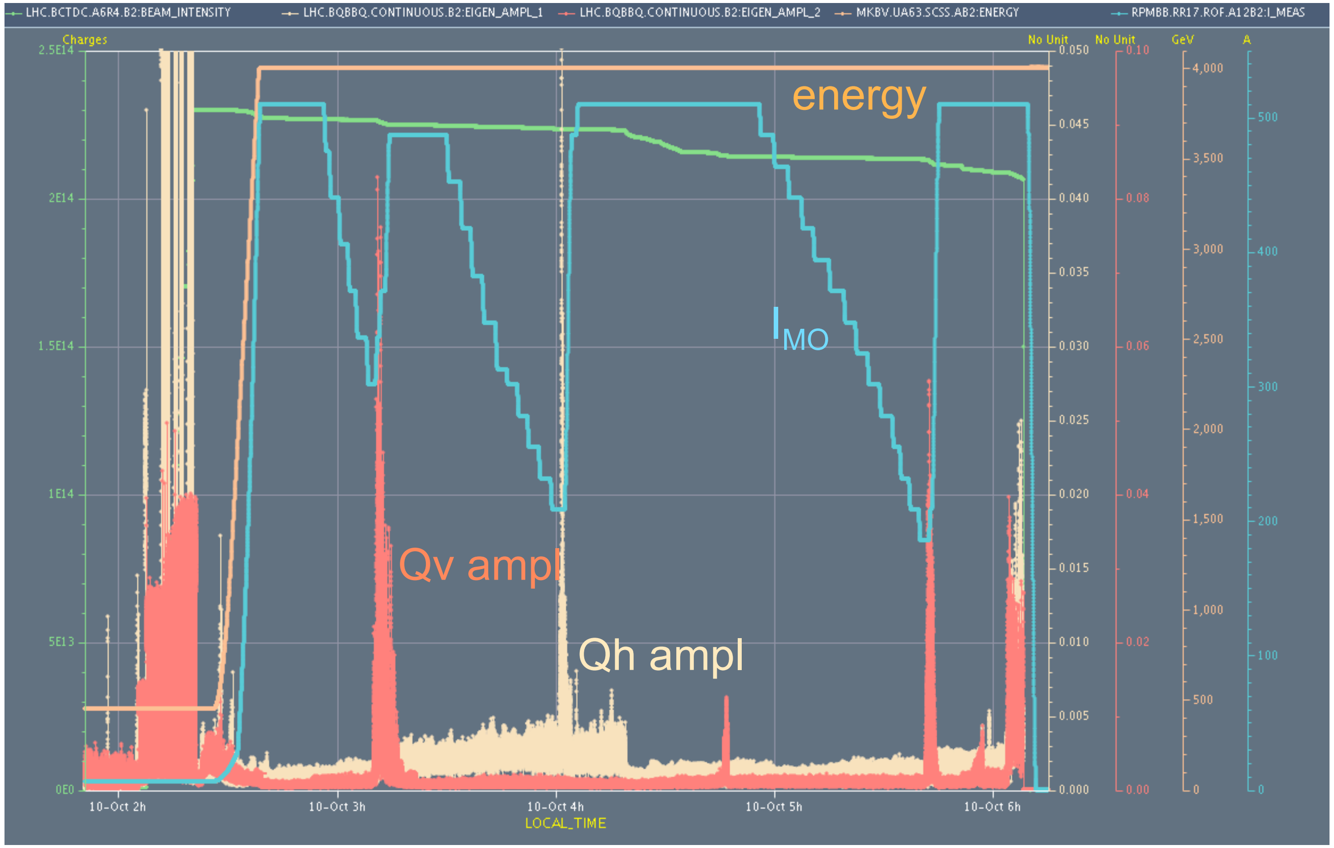
- next iteration: 9 m to 0.6 m
  - can see from luminosity dips that orbits moved more than hoped for

- conclusions
  - technically it works
  - more time to be invested in the orbit setup during commissioning
  - challenge: keep the beams in collision without stopping too frequently
  - need to partly rely on reproducibility

instability threshold with one beam

N. Mounet, E. Metral, A. Burov et al.

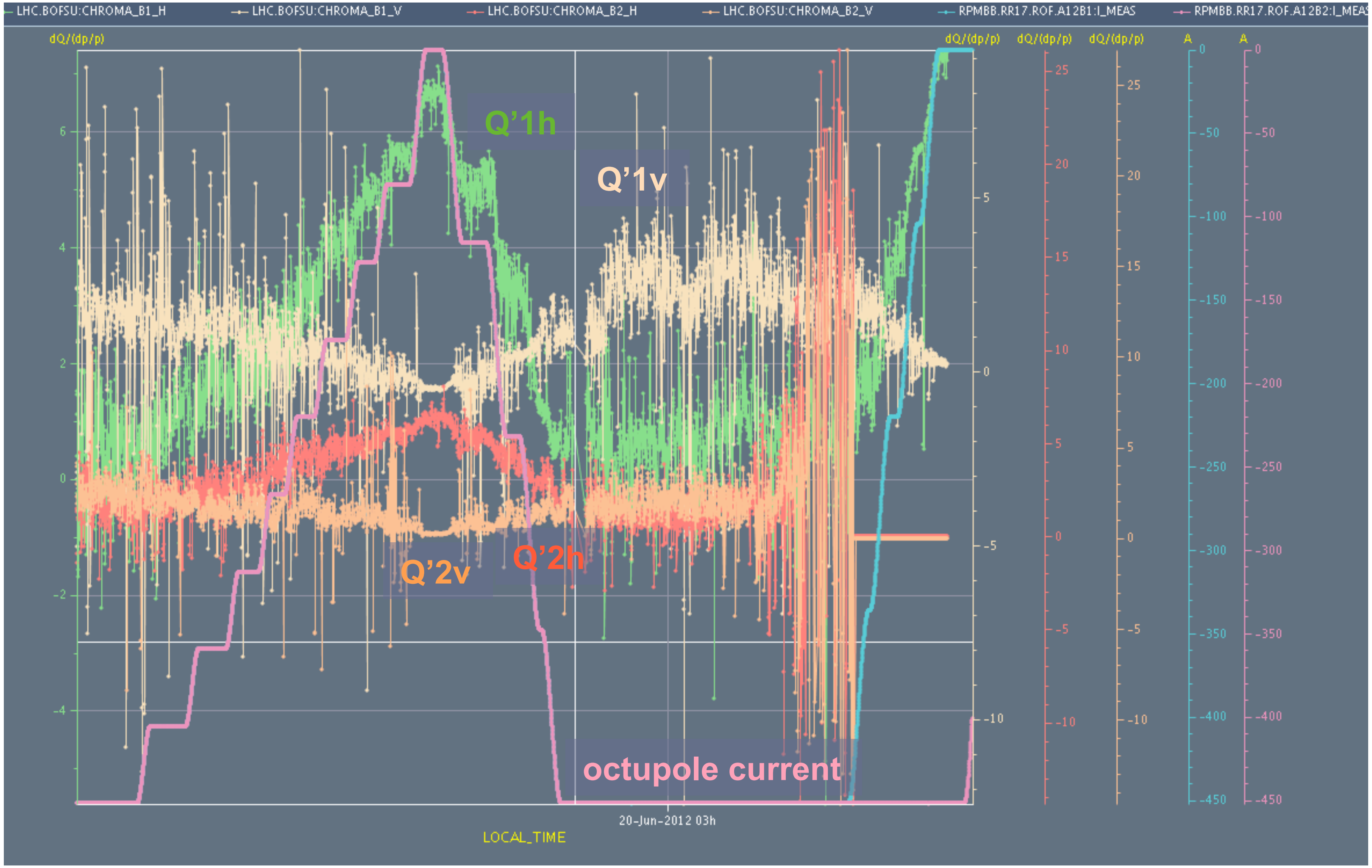
- 4 fills in 2 MDs, measurements done on beam 2 only
  - MPP class: C (and Machine Protection Panel suggested ring 2)
  - tested both octupole polarities
- scans for instability threshold with octupole strength and different chromaticity and transverse damper gains, before and after squeeze



octupole strength scans

G. Papotti, W. Herr, N. Mounet et al.

- first measurement of chromaticity dependence on octupole strength (feed-down)
  - fundamental for studies on stability parameter space
  - variation of up to 5 units in H, 2 units in V, for $0 < I_{oct} < 450$ A



long-range beam-beam studies (1)

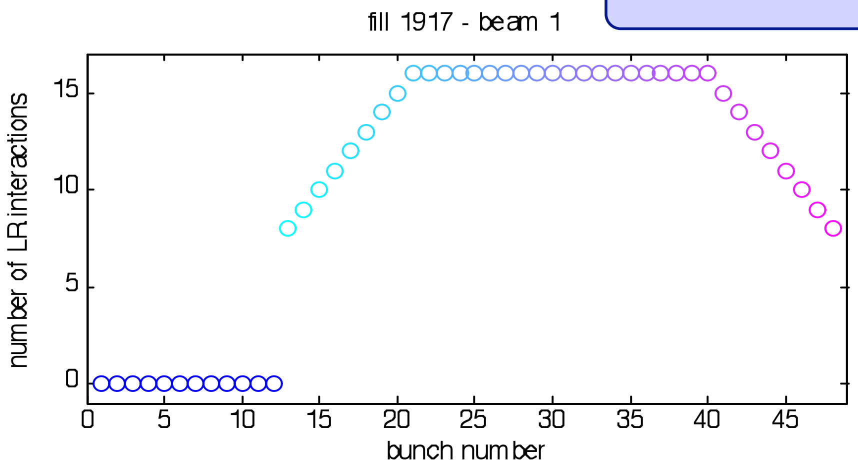
W. Herr, T. Pieloni, G. Papotti et al.

- aim: characterize the effect of reduced crossing angles on losses due to long-range encounters
- progressively reduce crossing angle from operational configuration to reduce separation and observe reduction of dynamic aperture
  - move tertiary collimators accordingly to guarantee correct hierarchy and protection
  - MPP classification: C
- repeated in different configurations for scaling laws:
  - for different beta*/normalized separation (2011 and 2012)
  - for different intensity per bunch

long-range beam-beam studies (2)

W. Herr, T. Pieloni,
G. Papotti et al.

- train of 36b, colliding in IP1/5
- $\beta* = 0.6$ m



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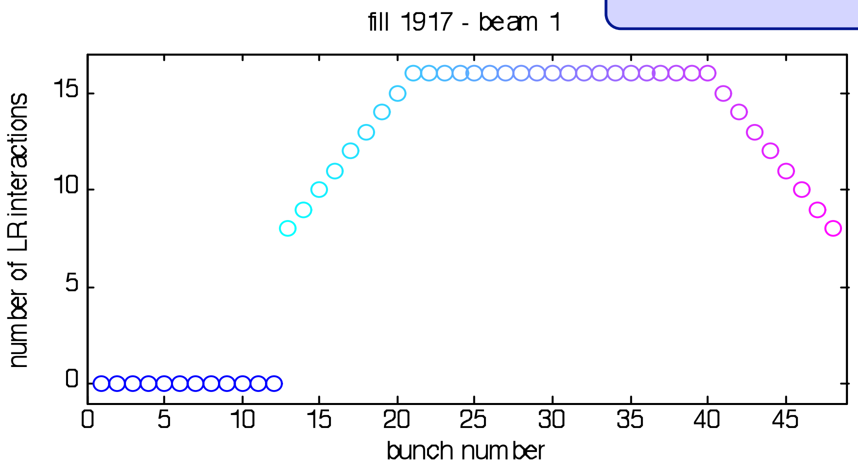
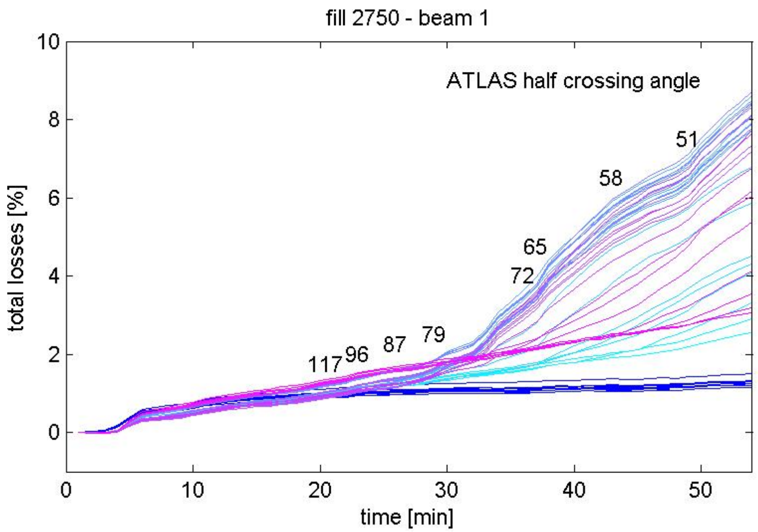


- loss onset different for different number of long-range interaction, integrated losses proportional
  - very reproducible results, in particular on the number of long-range interactions



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W. Herr, T. Pieloni, G. Papotti et al.

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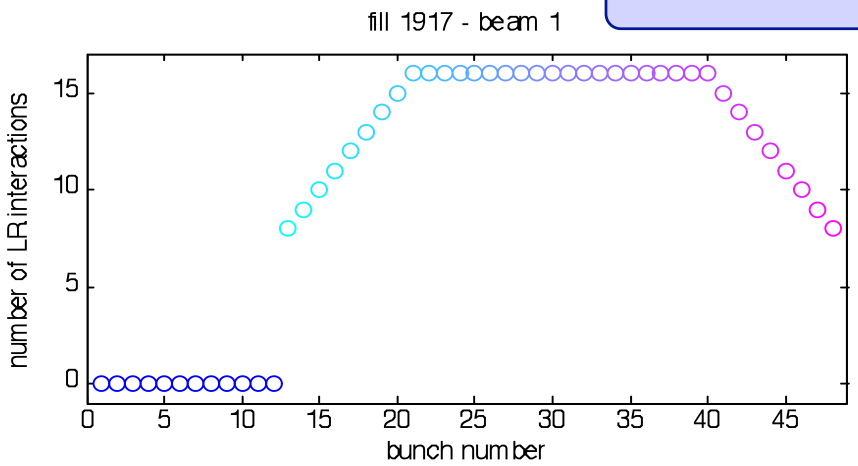

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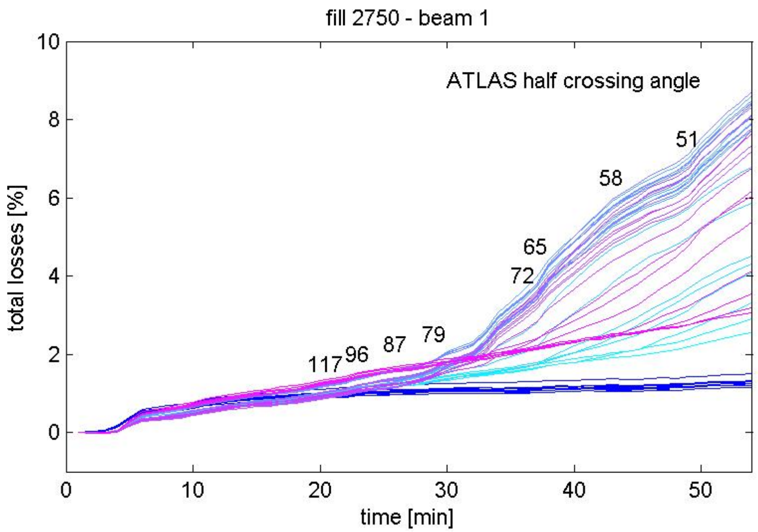
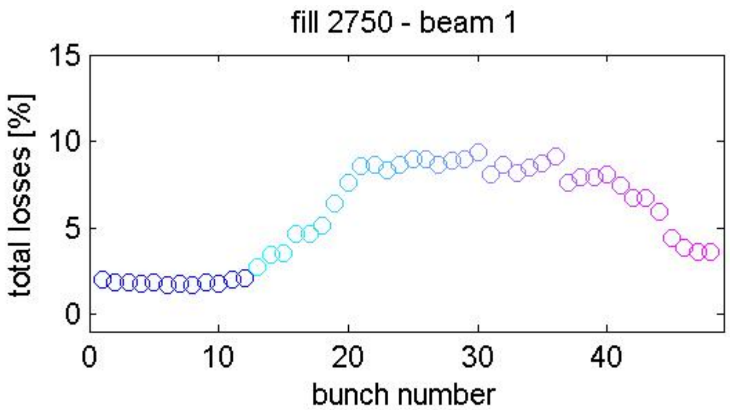
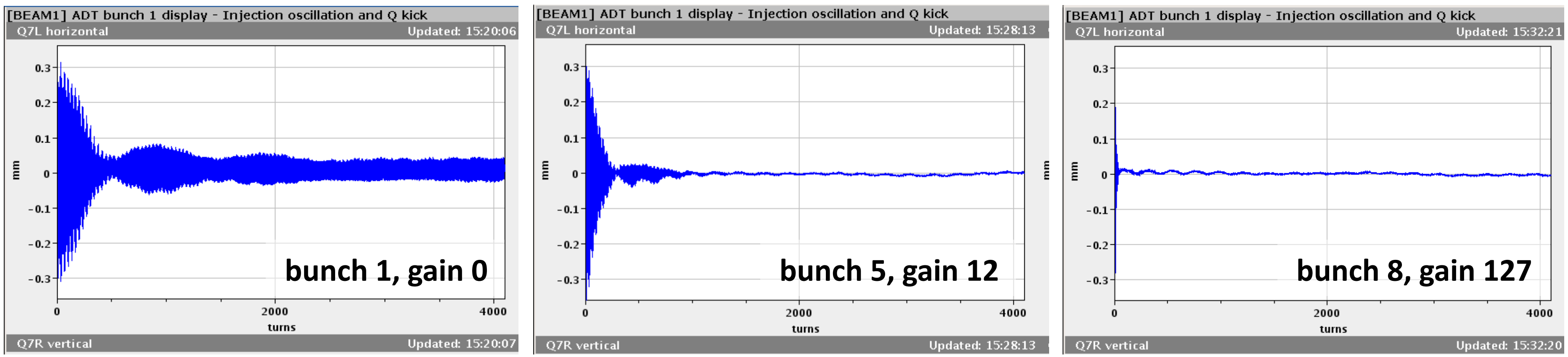




transverse damper developments

W. Hofle,
D. Valuch et al.

- extremely flexible system, used for many different purposes
  - damping of transverse oscillations (at injection and during cycle)
  - abort gap cleaning
  - injection gap cleaning
  - selective blow up for emittance increase or for loss maps
  - issue with tune measurement compatibility
    - lately: lower gain on 6 bunches for BBQ (gated), higher on the other bunches for stability and emittance preservation

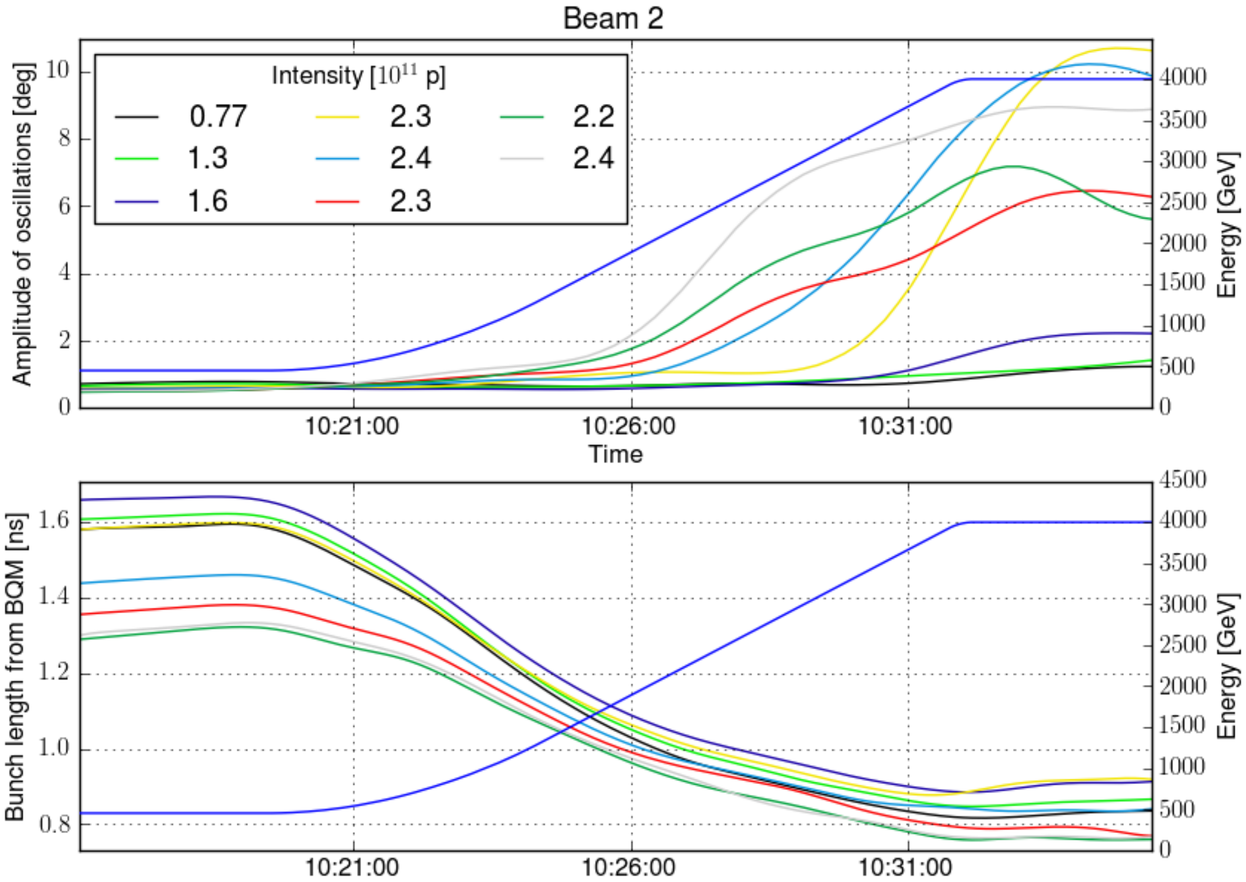


example: commissioning of the batch-by-batch gain modulation

longitudinal dynamics

E. Shaposhnikova,
J. Mueller et al.

- thorough studies on loss of Landau damping
  - instability threshold dependence on emittance, intensity and energy, with phase loop on and off
  - shorter bunches or higher intensities become unstable earlier in the ramp



remaining studies for 2012

- quench tests
  - 2 days at end of run, Feb 2013
  - with wire scanners
  - with orbit bumps
  - with transverse damper
- 25 ns scrubbing run (not on MD time at injection)
  - how much time needs to be scheduled after the long shutdown?
- e-cloud scaling to top energy
  - in parallel, UFO observations: they seemed much worse with 25 ns
- long-range scaling with 25 ns (twice the number of interactions)
  - needed for required separation
- flat bunches for heating reduction

conclusions

- 2012 LHC MDs extremely successful
  - efficient use of beam time, scheduled in agreement with priorities
  - credits to MD teams, OP crews and injectors for the achieved results

- 2012 achievements:
  - some records
    - beta* from 10 cm (ATS) to 1 km (de-squeeze)
    - pile-up up to ~70 (design is 20)
    - stored high brightness beams: 3e11 ppb in 2.2 um at 4 TeV
    - large Piwinski angle: $\phi_{piw} = 1.1$
  - feasibility of levelling by β^*, 7 TeV collimator settings, dynamic aperture found in agreement with prediction, improved understanding of instability thresholds, and hardware systems …

- remaining priorities for this run
  - quench tests, 25 ns e-cloud at injection and top energy, UFOs, long-range beam-beam scaling laws, …

ideas for studies at RHIC

- octupoles and instabilities (W. Herr and G. Arduini)
  - disentangle the issue of Landau damping with head-on beam-beam or separated beams, octupoles, transverse damper, chromaticity
  - needed in particular for HL-LHC to define the design of the octupoles
- collisions with flat beams? (W. Herr)
  - different aspect ratios from beta* (optics flexibility?)
- electron lenses (W. Herr)
  - feasibility of fast tune changes, bunch-by-bunch
  - full or partial compensation of head-on beam-beam effect on performance and instabilities
  - explore the effect of the noise from the e-beam on the head-on beam-beam tune shift
- tune spread from the BTF measurement? (W. Herr)
- experiments on effect of external noise (e.g. power supplies, UPS, …) on emittance preservation (G. Arduini)
  - e.g. improve tools, analysis

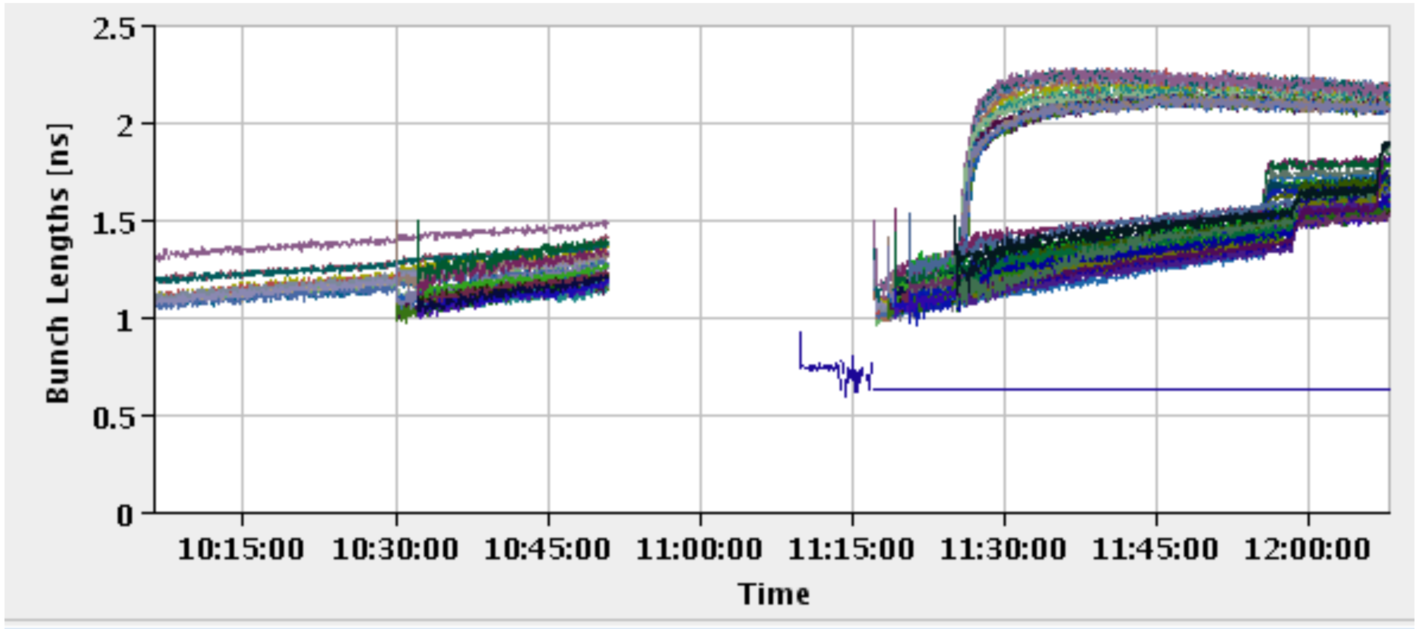
spares

- batch-by-batch blow up
- dynamic aperture
- de-squeeze
- ATS
- injection of SPS Q20 single bunches
- high pile-up record
- fast losses with transverse damper and tune kicker

RF development examples

P. Baudrenghien,
M. Jaussi,
T. Mastoridis et al.

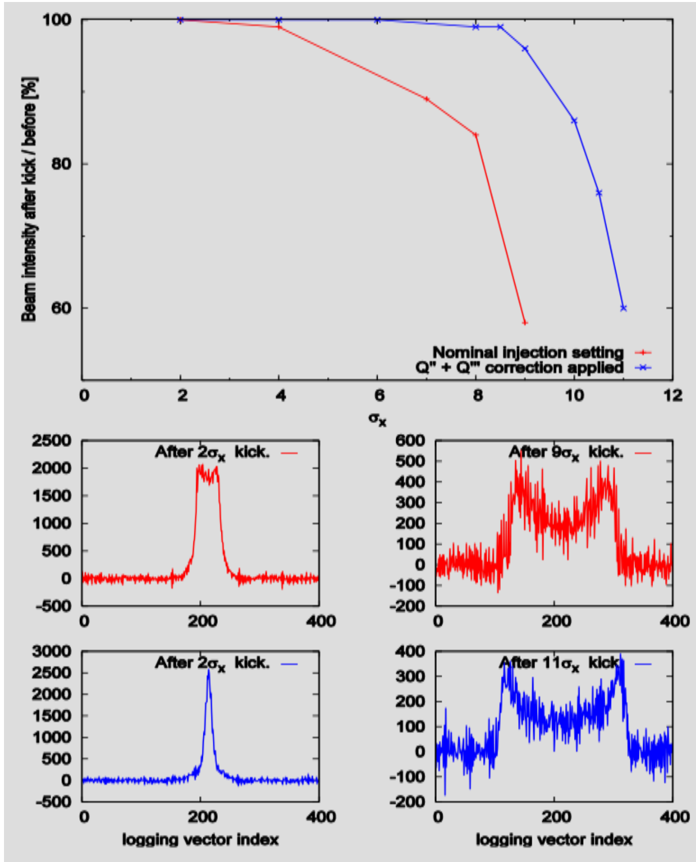
- batch-by-batch longitudinal blow up
  - can blow-up the the injected batch without touching the circulating beam
  - possible improvement in luminosity via decreasing the transverse emittance increase due to IBS
  - more developments required to automate the procedure for op



dynamic aperture

F. Schmidt,
M. Giovannozzi,
R. de Maria et al.

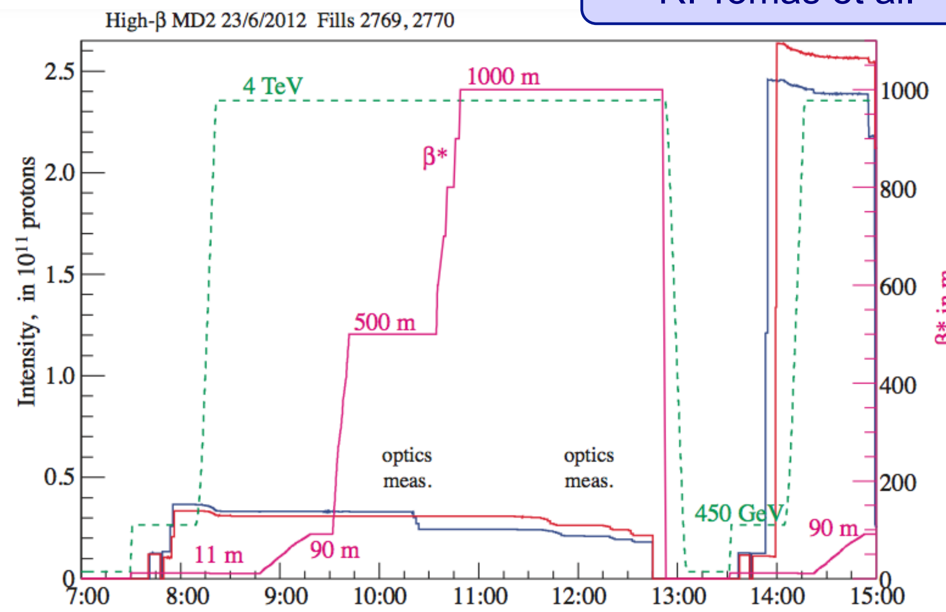
- large kicks with the aperture kicker for:
  - I: LHC as is and in particular the standard MO settings.
  - II: same machine except that the MO have been switched off and a full Q'' and Q''' (albeit we have to deduce this from the cancellation of the decoherence)
- demonstrate difference between the 2 cases:
  - I: **Large detuning with amplitudes and a DA due to a combined driving of the 4Qx and 3Qy resonances.** Large nonlinear coupling observed. Kicks up to 9 sigma.
  - II: **Detuning with amplitude very small ~1e-3 even for large kicks**, 12 sigma kicks in H, V and H&V variation of amplitude. Limited by collimation/ injection protection. Confidence that we can disentangle losses from scraping and slow particle losses due to the DA.
- estimate of the DA between **10 and 12 sigma**
- in parallel on the other beam: studies on intensity evolution of blown up bunches for different decapole and octupole strengths

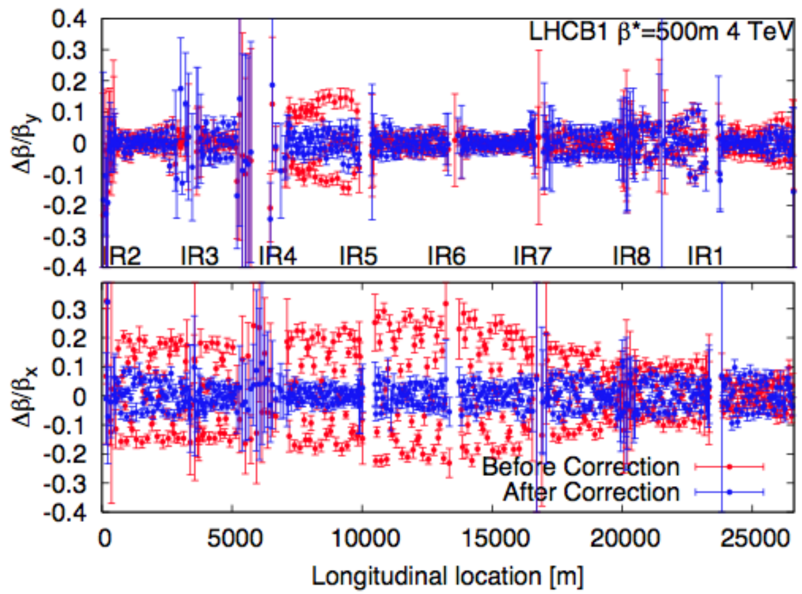


de-squeeze

H. Burkhardt,
S. Cavalier,
R. Tomas et al.

- 3 fills so far
  - de-squeeze 90 -> 500 m flat machine, measure + correct optics, loss-less
  - separation on, re-measure 500 m, first successful attempt to 1000 m done (with optics measurements)
  - started with 2 nominal bunches, ok to 90 m
- next steps in physics time
  - finding collisions, non-trivial at high-β (corrector and aperture limits) requires ~ nominal intensities
  - minimum emittance (~ 1 μm, without scraping)
  - roman pots very close to beam

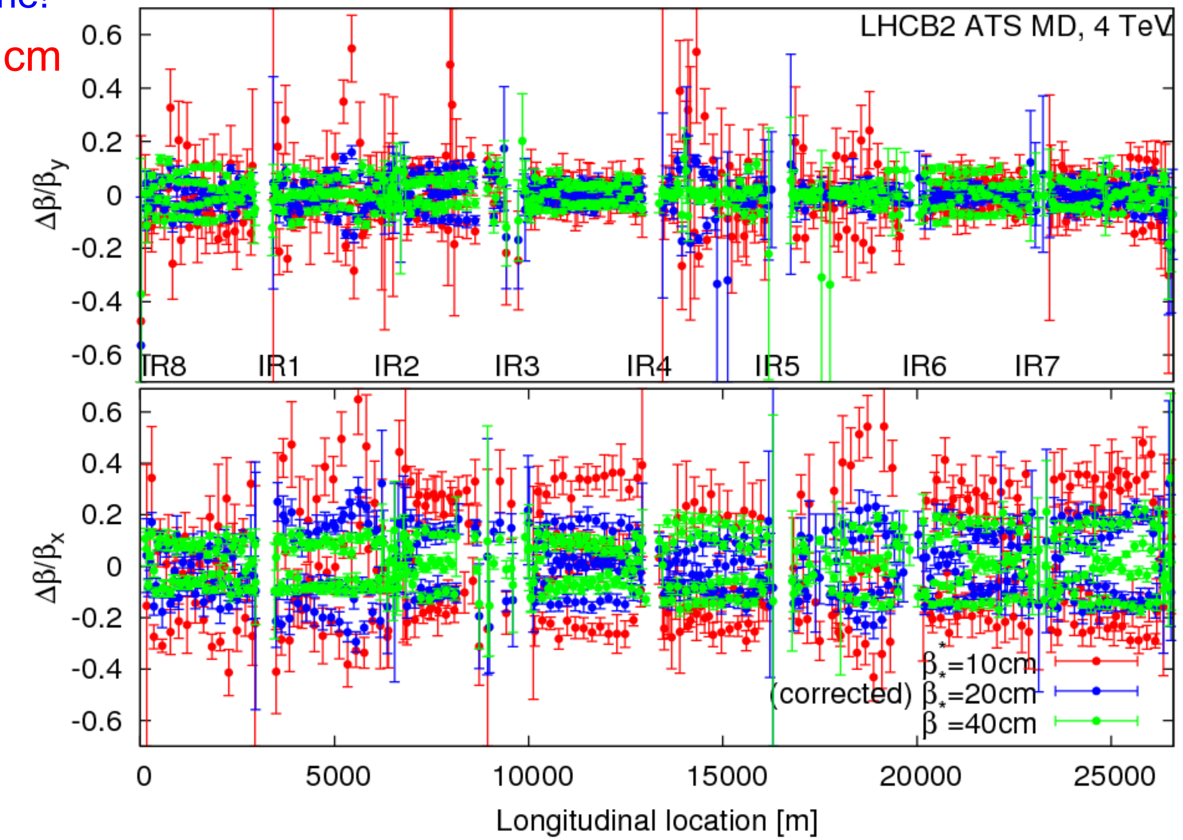




Achromatic Telescopic Squeeze

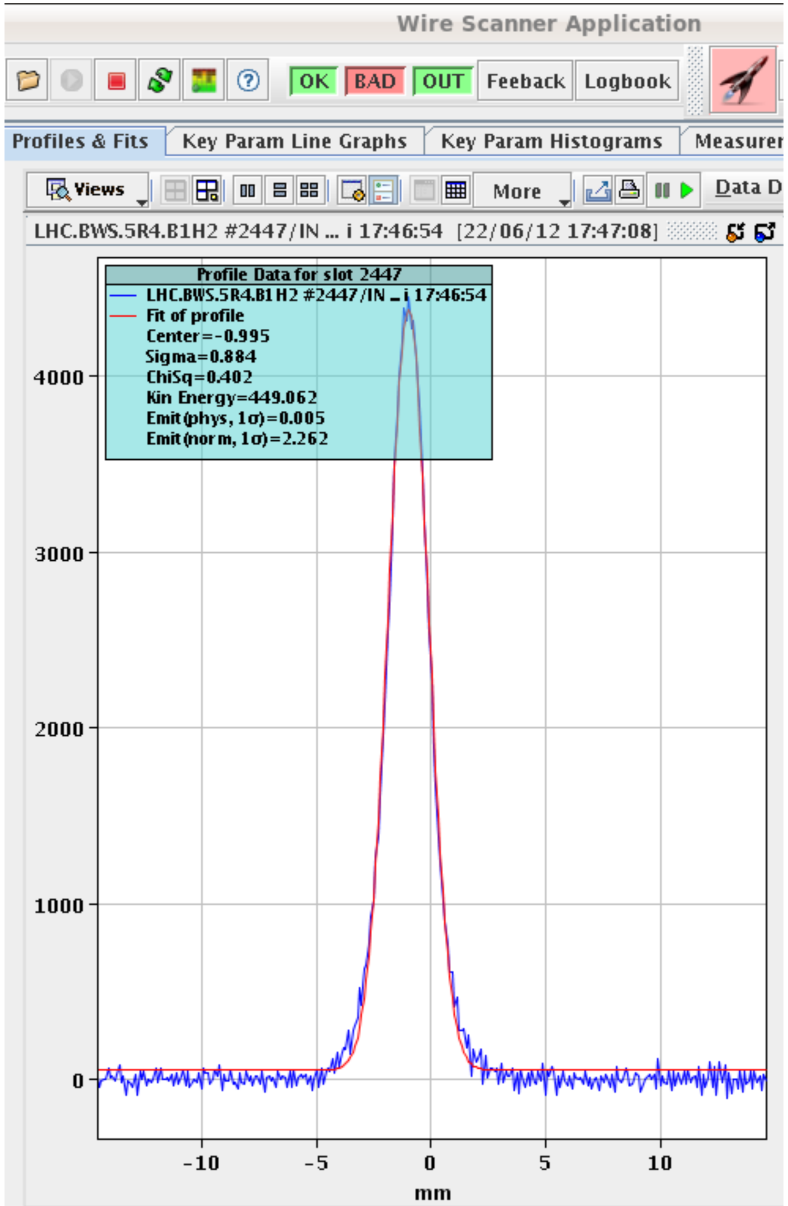
S. Fartoukh,
R. de Maria, L. Ponce,
M. Solfaroli et al.

- achieved (without crossing angle, parallel separation at IP1/5)
  - "pre-squeeze" IR1&5 to β^* = 40 cm
  - squeeze IR1&5 to β^* = 10-15 cm
    - beam 2 reached β^*=10 cm
      - β^*=10 cm → β_{max} = 23.8 km in the triplet (21.1 km for BPMS)
      - "... β^* was probably around 12.5(V)-14.5(H) cm, so still 5mm better than the HL-LHC baseline!"
    - beam 1 lost at β^*=14 cm
      - bad manual trim
- to be redone with corrected beta-beating, coupling
  - plus tune scan to try and improve lifetime



injection of Q20 single bunches

H. Bartosik,
Y. Papaphilippou,
B. Goddard et al.

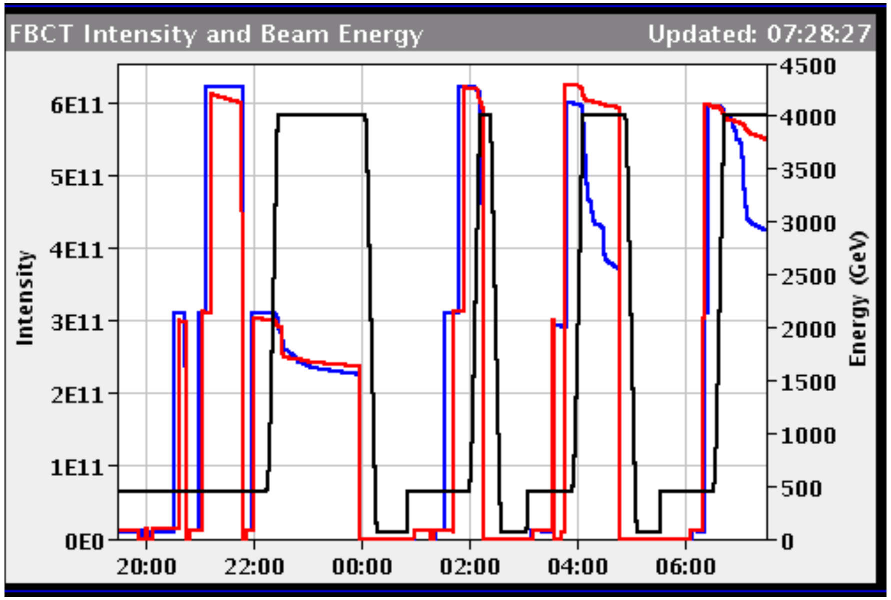


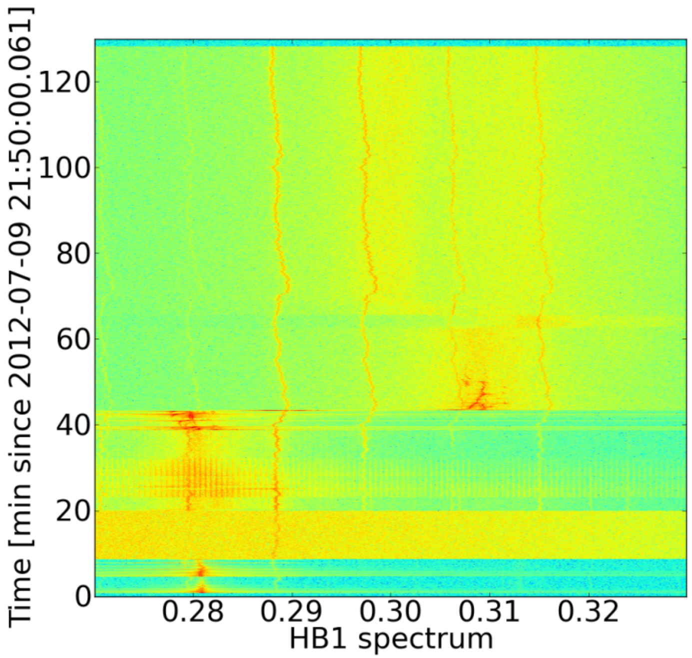
- new SPS Q20 optics allows 3e11 ppb in ~2 um emittances
  - lower γ_t allows bigger margins for instabilities
- in MD: transfer line setup, first injections of single bunches
  - ongoing in operations for bunch trains

high pile-up

R. W. Assmann,
W. Herr,
T. Pieloni et al.

- injected high brightness single bunches from new SPS Q20 optics
  - ~3e11 ppb, 1.5-2 um at injection
  - ΔQ_{BB} > 0.012/IP
- 4 short fills
  - fill 4: achieved pile-up 70 in ATLAS and 65 in CMS



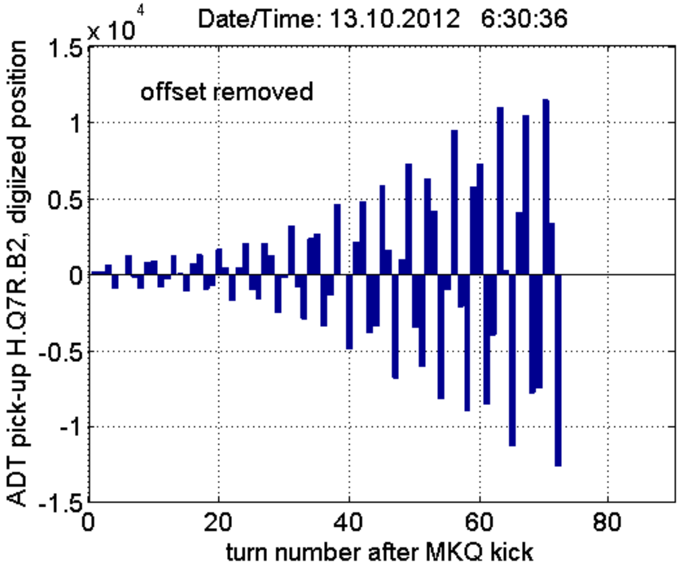


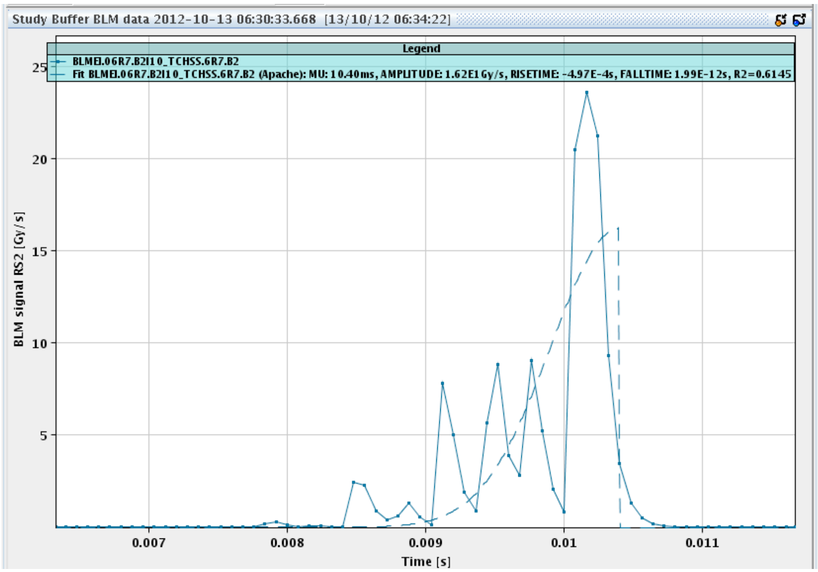
- beams were touchy
  - instabilities and losses observed
  - helped by increase in chromaticity (+3 units) and in target bunch length (1.4 ns)
  - managed 2.2 um in collisions, losses <5%, beam 2 only
    - feasibility proven! but work needed

fast losses with ADT and MKQ

A. Priebe, D. Valuch, M. Sapinski et al.

- investigate ADT-generated losses as during MD2, plus the tune kicker used for initial excitation of the beam
- tests at injection with different ADT gain and MKQ strength and collimator settings (final: all but one jaw retracted)
  - none of these gave important signal in BLMs on cold magnets, so decided to go on with the ramp
- at the flat top, tried different settings and managed to dump on BLMs in IR7 (on TCP, TCSG, TCLA, MBW)
  - the rise time of these losses (~0.5 ms) is the closest to UFOs time structure





MD categories and requests

- 76 requests already for Evian workshop 2011
  - some more through the year
- e.g.:
  - RF, ADT and long. dynamics (12)
  - collimation (11)
  - optics (9)
  - impedance (8)
  - beam-beam (7)
  - quenches (6)
  - injection (4)
  - ions or p-Pb (3)
  - …

	title	time [h]	energy	spacing [ns]	current	requestor	theme	MP class	
1	MKI UFO	8	450	25	high	Tobias Baer	after LS1	C	
2	ATS optics	16	4000	NA	low	Stephane Fartoukh	HL-LHC	A	
3	bb limit HO with unequal beams	16	450/4000	NA	medium	Herr / Papotti	HL-LHC	B	
4	bb limit, LR separation	24	4000	25+50	medium+	Herr / Papotti	HL-LHC	C	
5	bb limit, LR intensity	8	4000	50	medium+	Herr / Papotti	after LS1	C	
6	large Piwinski angle	16	450	NA	medium	Fartoukh / Zimmermann	HL-LHC	A	
7	BI MDs	91	450 & 4000	NA	medium	BI team	2012	B (and A)	
8	CaC	8	450	NA	medium	Assmann / Fartoukh	HL-LHC	A	
9	Transverse noide & coh. bb	16	4000	50	medium+	Herr / Papotti	2012	C	
10	bb emittance growth due to transv. noise	16	4000	NA	medium	Buffat et al	HL-LHC	B	
11	Source of transverse emittance blow up	16	450/4000	50	high	Arduini	2012	C	
12	LR beam-beam with flat beams	24	4000	50	medium+	Herr / Papotti	HL-LHC	C	
13	Tune close to 1/2 integer	16	4000	50	medium+	Calaga et al	HL-LHC	C	
14	High pile up	8	4000	NA	medium	Fartoukh	HL-LHC	B	
15	HV passive compensation	16	4000	25+50	medium+	Calaga et al	HL-LHC	C	
16	compensation of IR nonlinearities	12	4000	NA	low	Tomas	2012	A	
17	Quench margin at top energy	16	4000	50	medium+	Redaelli / Wollmann	after LS1	C	
18	Halo scraping	0.5	450/4000	50	high	Wollmann / Burkart	after LS1	C	EOF
19	Transverse emittance blow up at injection	10	450	50	medium+	Metral / Mounet	2012	C	
20	TCBI at flat top and octupole stabilization	20	4000	25+50	medium+	Mounet / Metral	after LS1	B/C?	
21	Impedance budget at injection	6	450	NA	low	Biancacci	2012?	A	
22	Multibunch tune shift at flat top	8	4000	25+50	medium+	Mounet / Metral	2012?	B	
23	Multibunch tune shift at injection	8	450	25+50	medium+	Mounet / Metral	2012?	B	
24	TCBI at flat top and octupole stabilization	1	4000	50	high	Mounet / Metral	after LS1	D	EOF
25	Beam losses at injection	16	450	25	medium+	Bartmann / Bracco	after LS1	B	
26	Probing the single bunch limits in LHC	6	450	NA	medium	Salvant	HL-LHC	B	
27	Quench limit investigation	16	450	NA	low	Bracco et al	2012	C	
28	Asynchronous dump in collimation set up	8	450	NA	low	Rossi / Lari / Cauchi	after LS1	C	
29	Scraping scans for beam shape	8	450/4000	NA	medium	Wollmann / Burkart	after LS1	B	
30	Protection from long devices	16	450/4000	NA	low	Bartmann / Bracco	2012	A	
31	LHC transverse impedance	10	450/4000	NA	medium	Redaelli / Salvant	2012	B	
32	Injection matching and emittance preservation	16	450	NA	low	Kain	2012	B	
33	Impedance and beam heating of long protetion devices	16	450	50	medium+	Goddard	2012	B	
34	LHC transfer line stability	16	450	50	medium+	Kain	2012	B	
35	Wire scanner quench test at flat top	8	4000	50	medium+	Sapinski	2012	C	
36	Optimization of ADT in the ramp	12	450/4000	50	high	Hofle	2012	B	
37	Noise properties of ADT with FB on and off	6	450	25+50	medium+	Hofle	after LS1	A	
38	Residual tune signal in damper signal	6	450	25+50	medium+	Hofle	after LS1	A	
39	ADT Q/Q' diagnostics possibility	[illegible]	450/4000	50	high	Hofle	2012	B	
40	Collimation studies with different settings	24	4000	50	medium+	Assmann	after LS1	B	
41	Quench test at injection energy	8	450	NA	medium	Priebe	2012	A?	
42	Loss maps with transverse damper	8	450/4000	50	medium+	Salvachua	2012	B or C	
43	Collimation with beta*=40 cm	8	4000	NA	medium	Bruce	HL-LHC	B	
44	Fast collimator setup at 3.5 TeV	8	4000	NA	medium	Valentino	2012	B	
45	intensity limitations for 25 ns operation	24	450/4000	25	medium+	Arduini	after LS1	B	
46	Operational development MD	48	450/4000	NA	low	Wenninger	after LS1	A or B	
47	Quench test at nominal energy	8	4000	NA	medium	Priebe	2012	C	
48	Scraping with tune excitation	16	450/4000	NA	medium	Bruce	HL-LHC	A or B	
49	Nonlinear beam dynamics	12	450	NA	low	Giovannozzi et al	HL-LHC	A	
50	Transfer & injection of high brightness bunches w SPS Q20	16	450	50	medium+	Bartmann et al	after LS1	C	
51	Single bunch parameter evolution	?	4000	50	high	Papotti	2012	A	
52	Effective lontiudinal broadband impedance	6	450	NA	medium+	Shaposhnikova	after LS1	B	
53	Movements IT with beam at injection	8	450	NA	low	Wenninger	2012	A	
54	Sensitvity of QPS thresholds to FB systems	8	4000	50	high?	Denz et al	after LS1	A	
55	Loss of Landau damping during ramp	6	4000	NA	medium+	Shaposhnikova	2012	B	
56	Ion collimation loss mitigation	16	4000	100 or 200	medium+	Jowett	2012	C	
57	Proton lead intensity limit	16	450/4000	100 or 200	medium+	Jowett	2012	C	
58	Proton collimation loss mitigation	16	4000	50	medium+	Jowett	after LS1	C	
59	De-squeeze to beta*=500	8	4000	NA	low	Burkhardt	2012	A	
60	Scraping to 1 micron emittance at to energy	8	4000	NA	medium	Burkhardt	2012	A	
61	RF cavity non-linearities	16	450/4000	NA	medium	Calaga	HL-LHC	A	
62	Longitudinal blow up studies	16	450/4000	50	medium+	Baudrenghien	2012	B	
63	RF feedback optimization with circulating beam	4	450/4000	50	medium	Baudrenghien	2012	B	(EOF)
64	Commissioning of longitudinal damper	16	450	50	medium+	Baudrenghien	2012	B	
65	Commissioning of p-Pb rephasing using p	8	450	50	medium+	Baudrenghien	2012	B	
66	Longitudinal stability for batch	16	450	50	medium+	Baudrenghien	after LS1	B	
67	Voltage modulation to minimize klystron power	16	450/4000	50	medium+	Baudrenghien	after LS1	B	
68	Longiudinal stability of batch	16	450	50	medium+	Baudrenghien	after LS1	B	
69	Aperture measurements at 3.5 TeV w ADT blow up	8	4000	NA	medium	Redaelli	2012	B	
70	Collimation cleaning during the ramp w ADT blow up	8	4000	NA	medium	Redaelli	2012	B	
71	Fast beam losses at the collimators	8	450/4000	NA	medium	Redaelli	2012	B	
72	Combined ramp & squeeze	8	450/4000	NA	low	Redaelli	after LS1	A	
73	Luminosity leveling with dynamic beta* change	8	4000	NA	medium	Redaelli	after LS1	C	
74	LHC linear chromaticity	6	450	NA	low	Tomas	2012?	A	

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